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A Methodology for the Evaluation of Structural Design Software for DOS-Based Microcomputers

by
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The missions of the U.S. Army Corps of Engineers and installation Directorates of Engineering and Housing require structural design engineers to produce high-quality designs with efficiency and accuracy. Therefore, the Army has an interest in the productivity and quality enhancements offered by structural design computer software.

This report presents a methodology for evaluating the performance of commercially available structural design software for DOS-based microcomputers. Careful evaluation of such software is necessary because the quality of these products varies widely, and these differences may not be apparent without systematic evaluation by the potential user. Significant savings in the design process can be realized if a high-quality software program is used for its intended purpose.

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FOREWORD

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COL Daniel Waldo, Jr., is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

CONTENTS

A METHODOLOGY FOR THE EVALUATION OF STRUCTURAL DESIGN SOFTWARE FOR DOS-BASED MICROCOMPUTERS

1 INTRODUCTION

Background

The missions of the U.S. Army Corps of Engineers (USACE) and Army installation Directorates of Engineering and Housing (DEHs) require structural design engineers to produce high quality designs with efficiency and accuracy. Therefore the Army has an interest in the productivity and quality enhancements offered by the application of computer software to the structural design process.

Many structural design software programs have recently been developed and are now commercially available for microcomputers. Most of these programs have been developed for the design of a particular type of structural member (e.g., steel roof trusses, steel beams, reinforced concrete slabs) or a specific design methodology. Significant savings in the design process can be realized if the most appropriate software is selected and used for its intended purpose.

The software term "CAD" is generally understood to mean computer-aided design or computer-aided drafting. In this report, however, CAD refers exclusively to computer-aided design. The term *design* refers here to the detailed or integrated design of a structure. As such, structural design is a complicated process; structural design packages must therefore be much more complex than programs that perform only structural analysis.

A large number of commercial CAD packages have been introduced in recent years and many of them claim to have extensive capabilities. The first reaction of potential buyers and users of such packages should be caution—to analyze their needs versus the stated capability of the software. The quality and applicability of programs varies widely. Industry authorities have pointed out that many structural design programs do not take full advantage of the interactive capabilities of microcomputers.[1] Some packages seem to be simply downloaded from mainframes to microcomputers. Others require the user to perform certain computations in another program and manually enter the results into the computer.

The potential user of CAD software should be concerned with three problems associated with many commercial software packages: (1) generally speaking, software development is behind hardware innovations, (2) many CAD packages are developed by software engineers rather than structural design engineers who are also qualified software engineers, and (3) there is a tendency toward arbitrary pricing of commercial software packages.

It would be naive to follow the adage "you get what you pay for," but one must be somewhat skeptical of low-priced commercial CAD packages. There are, however, many public-domain and noncopyrighted computer programs developed at research organizations and universities that can be obtained free of charge or at a nominal fee. Some of these research-based programs are not well documented or maintained, but many are innovative and sometimes even the precursors of commercial

[1] H. Falk, *Microcomputer Software for Civil Engineers* (Van Nostrand Reinhold Co., 1986); H. Adeli, "Book Review: Microcomputer Software for Civil Engineers," *Microcomputers in Civil Engineering*, Vol 2, No. 4 (1987b).

packages. If a program is not well documented or maintained, it should only be used by those with extensive programming experience.

Some noncommercial programs are well documented and maintained, however. The Computer Aided Engineering Division of the Information Technology Laboratory at the U.S. Army Waterways Experiment Station (USAWES) has developed numerous engineering software packages that are available to Government engineers. The Appendix to this report lists relevant software available from USAWES. Government engineers should consider the availability of this software before purchasing commercial packages.

There is a broad spectrum of design problems, and for each class of problems a large number of project-specific factors must be considered and weighed. This makes the evaluation and selection of CAD software a formidable task. The U.S. Army Corps of Engineers Computer Aided Structural Engineering (CASE) Project and the USAWES Information Technology Laboratory are available to advise Government engineers on the most appropriate software for large project needs, but the installation-level engineer may still need to evaluate microcomputer-based CAD packages.

A methodology for the evaluation of CAD software is necessary because the quality of these products varies widely, and this difference may not be apparent without systematic evaluation by the potential user.

Objective

The objective of this study was to develop a methodology for evaluating the performance of commercially available structural design software configured to run on DOS*-based microcomputers.

Approach

This report presents a two-step methodology for general evaluation of commercial structural design software packages. The first step, presented in Chapter 3, provides a quick means for the initial screening of the software packages. The second step, presented in Chapters 4 and 5, employs benchmark criteria and tests for the purpose of final evaluation and rating of a selected number of packages. In the final step, presented in Chapter 6, a tabular procedure is developed for summarizing and presenting the evaluation information. Without labeling any single package as the "best," this procedure is intended to guide the potential user toward the selection of the most appropriate one. The methodology developed in this work takes into consideration that some degree of subjectivity is inevitable in the final selection of the CAD package.

Scope

This report presents a general methodology for evaluating structural design software. Chapter 4 includes some special considerations for various design categories, but the evaluator may have a number of additional considerations unique to his or her design needs.

*The widely used disk operating system for IBM-compatible microcomputers.

2 SOURCES OF SOFTWARE INFORMATION

The best way to determine what software is available is to examine professional and industry journals that review such packages. Some of the more authoritative sources include the following:

- *CE Computing Review.* This is a monthly newsletter launched by the American Society of Civil Engineers (ASCE) in June 1989. It promises to publish reviews of software packages in various fields of civil engineering, including structural engineering.

- *Microcomputers in Civil Engineering.* This is a scholarly international journal published quarterly by Elsevier in New York. It publishes reviews of advanced software packages such as expert system programming environments. Review articles in the journal present the state of the art and practice of software engineering. The journal also has a section where contributors and readers share novel programming approaches, program subroutines or modules, or even complete programs.

- *Civil Engineering.* This monthly magazine published by ASCE includes many advertisements by software vendors in each issue.

- *ASCE News.* This monthly newsletter published by ASCE includes some advertisements by software vendors.

- *Modern Steel Construction.* This bimonthly magazine, published by the American Institute of Steel Construction in Chicago (AISC), includes advertisements mostly related to the design of steel structures.

- *Concrete International.* This monthly magazine published by the American Concrete Institute (ACI) includes advertisements mostly related to the design of concrete structures.

- *Microcomputer Software for Civil Engineers.* As mentioned previously, this book briefly reviews 195 software packages for various fields of civil engineering, including 21 for structural analysis and design, 26 for design of concrete structures, and eight for finite element analysis. The new edition of this book should include updated reviews.

- *PC CADD: A Buyer's Guide*, by D. Smith and E. Teicholz (Graphic Systems, Inc., 1985). This directory of major CAD software is aimed at the buyer.

3 PROCEDURE FOR INITIAL SCREENING

A timely and efficient initial screening of the software packages may be primarily based on a review of their manuals and literature provided by the vendors. The following sections discuss general criteria for the initial screening of software packages.

Design Category Identification

The first step in selecting the appropriate structural design software is to assess the designer's needs, which involves the identification of the particular design category.

The evaluator of these programs will also need to determine if his or her design needs require a general purpose design code for a particular type of construction, or a program for a very specific structural member. An example of a general purpose program is a three-dimensional steel truss design program, whereas a steel bar joist program is more specific. The general purpose program has the advantage of being more versatile and is thus useful for a greater spectrum of design applications. However the more narrowly focused (specific) design tools are simpler to use, more efficient for their specific application, and less expensive than the general purpose design tools. The decision of the appropriate design category will certainly limit the number of software packages being considered.

DOS-Compatible Hardware Requirements

The software should run on a DOS-based computer system. Note that some software called DOS-compatible by the vendor may actually require upgraded configurations or special peripheral hardware to work properly. Some newer packages may require protected mode operation with DOS computers based on the Intel 80286 or 80386 processor.

Graphics Capability

Interactive graphics capability should be considered an indispensable component of any state-of-the-art structural design package.

Software Developer Qualification and Track Record

Two elements are absolutely necessary in developing efficient and state-of-the-art software for designing structures: structural design experience and advanced knowledge of computer science. The software developing team should include an experienced design engineer, with a Professional Engineer license and graduate education, and a computer scientist (or engineer) with graduate level (or equivalent) education in computer science.

The software developer should be questioned about the software verification procedure. Has the vendor really verified that the software will perform as it is intended and advertised? The verification base should include at least several hundred dissimilar examples. The software developer should make a documented catalog of these examples available to the software evaluator for review and inspection.

It is important that the vendor demonstrate a track record. The software should be in commercial use, preferably for at least 18 months, with at least one implemented upgrade. This requirement may be waived for software packages aimed at design of unconventional and uncommon structures for which few packages are available. A list of the companies and organizations using the vendor's CAD package should be requested. This list should include the date of the software purchase by each company.

The software evaluator may wish to contact two or three individuals or organizations using the CAD package and inquire about the following:

- Ease of learning the package
- Ease of using the package
- Software support and responsiveness of the software developer
- Software enhancement and maintenance.

Documentation

A truly interactive program should be usable with very little reference to the software manual, but good documentation says a great deal about the quality of the program. A hard-to-follow, hastily written manual may indicate a hastily developed or poorly organized software package. It also indicates that the package has not been used and scrutinized by many users, or that the developer has not responded to user feedback about the documentation.

One important consideration in evaluating the software documentation is the description of its scope and capabilities. It should clearly describe what it can do as well as what it cannot do. Practically all the design software packages make certain assumptions. These assumptions must be clearly stated and brought to the attention of the user, both in the manual and the program itself. For example, in packages for the design of reinforced concrete slabs it is commonly assumed, but not always expressly stated, that the slab is centered over the columns.

User Support

The vendor must provide user support. This support should include telephone consultation and program updates. Updates become important if the CAD package is intended to be used for an extended period of time—say more than 2 years. The telephone consultation should be provided by a structural engineer who qualifies as a software expert, and not by a programmer who is also not a structural engineer. The software developer should report any bug found in the software to the user promptly, and provide an updated version of the software in a timely fashion.

Cost

Cost should not be the only criterion for selection of the software. The cost and capability must be weighed against each other. Vendors usually charge an annual fee for providing user support. This fee must be considered as part of the total cost of the CAD package.

4 BENCHMARK CRITERIA FOR EVALUATING STRUCTURAL DESIGN SOFTWARE

User Interface Issues

A structural design program must be interactive. With an interactive system, the designer or user is in charge and the system works as an "assistant."[2] It is the degree of interaction that determines whether the CAD program is useful and easy to use. An interactive program should ideally perform the following:

1. Carry out all numerical calculations.

2. Check for the consistency of design according to the selected design specification (e.g., Allowable Stress Design [AISC ASD, 1989] or Load and Resistance Factor Design [AISC LRFD, 1986] specification for design of steel buildings; or ACI specification for design of reinforced concrete structures.

3. Perform error checks extensively. For example, if the user mistakenly types in "360 ksi" instead of "36 ksi" for the yield stress of a steel wide flange rolled shape, the software package should bring the error to the user's attention, because a wide flange shape with a yield stress of 360 ksi is not available. (It should be noted, however, that there is a limit to such a capability and that expecting an entirely foolproof program is not realistic.)

4. Present possible alternatives to the user.

5. Prevent the user from entering data in violation of the design specification.

6. Inform the user about the ranges of practical values. (For example, in the design of steel plate girders, the ratio of the depth of the web plate to span length varies from 1/25 to 1/6, with the most common values between 1/15 and 1/10).

7. Provide practical values for the final design.[3]

Interaction between the user and the CAD package should take place through the use of hierarchical menus,[4] which should make the program easy to understand and use. The CAD package should be structured so the user can select various operations (e.g., creating the layout and configuration of the structure, structural analysis and stress check, members design, display the output) in any order desired. An on-line help facility should be able to describe various items in the menus and input/output variables.

An error recovery capability is also highly desirable. If for some reason (e.g., data input error, incorrect command, missing information) the software cannot find a solution, the problem should be brought to the attention of the user. After correcting the problem and providing the information requested by the user, the software should be able to continue without being terminated. Without such a capability, using the software to design complex or large structures would be quite frustrating; the user would have to start all over again each time an error causes the program to quit.

A program's error messages should describe the source of the error in a readily understandable statement.

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[2] H. Adeli, *Interactive Microcomputer-Aided Structural Steel Design* (Prentice-Hall, 1988a).

[3] H. Adeli, 1988a.

[4] H. Adeli and M.M. Al-Rijleh, " Computer-Aided Design of Trusses Using Turbo Pascal," *Microcomputers in Civil Engineering*, Vol 2, No. 2 (1987a); H. Adeli and M.M. Al-Rijleh, "A Knowledge-Based Expert System for Design of Roof Trusses," *Microcomputers in Civil Engineering*, Vol 2, No. 3 (1987b).

Interactive Graphics

A good example of interactive graphics for the design of two-dimensional framed structures on 16-bit microcomputers is presented by Hilmy and Morrow (1987), where the user and the machine interact through mouse-oriented menus. The user can create the structure layout, load the structure, and choose various options from menus quickly by using the electronic mouse.[5]

The graphics interface should have (1) a multiwindow environment and (2) graphics manipulation capabilities such as zooming, panning, and scaling.[6]

Data Entry Facility

Getting the required input data into the computer can be overwhelming for the design of large structures and is subject to human error. The data entry facility should include full screen editing: the user should be able to enter new data or revise the existing entries freely by simply moving the cursor to any location on the screen display.

Ideally, the CAD package should be capable of generating most of the input data automatically. Some of the finite-element packages provide an automatic mesh generation facility. It is also highly desirable to have an automatic load generation capability. But, these features require a knowledge-based approach to the development of a CAD package. In most of the presently available CAD packages, the user must manually calculate and enter the forces acting on the structure due to various loads.

An example of a program that can generate input data automatically is RTEXPERT, a prototype knowledge-based expert system for design of roof trusses. This program relieves the user of the tedious and error-prone chore of inputting values for the forces acting on the structure due to dead, live, snow, and wind loads.[7] The user needs only to select the type of roof materials and coverings (e.g., shingles, insulation, waterproofing, etc.) and the location of the structure being designed (city and state). RTEXPERT calculates all the various nodal loads automatically, using the knowledge of the shape of the truss, the weights of various roof covering materials commonly used in the United States, and a database containing the ground snow loads and basic wind velocities in major cities of the United States.

The CAD package should inform the user about the units of input data and keep track of units. The ability to work in both the U.S. customary and SI metric units may be desirable in certain applications.

Portability

The Intel 8086 and 8088 microprocessors were used in the first generation DOS-based computers. Now the more powerful Intel 80286 and 80386 microprocessors are widely used. Often structural design software does not take advantage of expanding hardware capabilities. Since the new generation microcomputers will supersede the earlier generation machines,[8] it is highly desirable that CAD packages be upgradable to the newer generation computer hardware capability while maintaining compatible data files.

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[5] S.I. Hilmy and K.E. Morrow, "Interactive Microcomputer Graphics Environment for Integrated Analysis and Design of 2-D Framed Structures," *Microcomputers in Civil Engineering*, Vol 2, No. 4 (1987).
[6] H. Adeli and M.M. Al-Rijleh, 1987a.
[7] H. Adeli and M.M. Al-Rijleh, 1987b.
[8] H. Adeli, "New Generation Microcomputers—Part I: 80386 Machines," *Microcomputers in Civil Engineering*, Vol 2, No. 4 (1987a).

Redesign Management

Design is an open-ended process that is accomplished by multiple steps. After creating an acceptable design a designer often goes back and makes improvements. The CAD package should provide a convenient means of redesign. For example, the designer may change the type of steel used in a steel structure. The CAD package should be able to redesign the structure without asking the user to re-input the data from scratch. This may be achieved through a series of redesign menus as described in the text by Adeli.[9]

Programming Environment

Development of powerful CAD packages often requires interfacing with several programming languages or environments. Graphics routines are developed most efficiently in assembly language or C. Engineering computations such as structural analysis are commonly done in FORTRAN or Turbo Pascal. Expert systems are developed using expert system programming tools or shells.[10]

Spreadsheet programs provide a convenient interactive programming environment and may be used for design of simple structures such as beams, columns, or footings.[11] Other interactive information management programming environments have been introduced into the market, one interesting example being HyperCard, developed for Apple Macintosh computers.[12] These new tools, however, have been developed mostly with business applications and not engineering design applications in mind. They are suitable for small design problems where extensive number crunching is not required.

Special Considerations for Various Design Categories

These considerations will depend on the particular class of structures.

For design of steel structures, the CAD package should have the capability of designing according to both the AISC Allowable Stress Design specification and the recently developed Load and Resistance Factor Design (LRFD) specification. It should also provide access to the recently expanded AISC hot-rolled sections database.

For design of reinforced concrete structures, the CAD package should offer both the working stress and ultimate strength design approaches. Most packages for design of reinforced concrete structures make assumptions about the reinforcement detailing. These assumptions must be carefully reviewed by the software evaluator. Restrictive assumptions can make the software hard to use, or even useless, for practical design applications. The input error check for reinforced concrete packages should point out any inconsistency with the code (such as too little or too much reinforcement, or inadequate stirrup spacing) to the attention of the user.

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[9] H. Adeli, 1988a.

[10] H. Adeli, "Expert System Shells," in H. Adeli, ed., *Expert Systems in Construction and Structural Engineering* (Chapman and Hall, 1988b).

[11] S.F. Steimer, "Microcomputers in Teaching: Steel Design With Spreadsheets," *Microcomputers in Civil Engineering*, Vol 1, No. 2 (1986); S.F. Steimer and D. Lo, "Formatted Spreadsheets for Engineers," *Microcomputers in Civil Engineering*, Vol 3, No. 2 (1988).

[12] M.A. Bhatti, "Developing Engineering Design Software Using HyperCard," *Microcomputers in Civil Engineering*, Vol 3, No. 2 (1988).

Software packages for design of bridges should have the capability of designing for the moving loads recommended by the American Association of State Highway and Transportation Officials (AASHTO) specifications.

Expert System Module

Knowledge-based expert systems (or expert systems for short) are computer programs that use artificial intelligence (AI) techniques to assist people in solving difficult problems involving knowledge, heuristics, and decisionmaking. The differences between conventional computer programs and expert systems may be delineated as follows:

1. Expert systems are knowledge-intensive programs.

2. Expert systems use heuristics in a specific domain of knowledge to improve the efficiency of the solution process.

3. In an expert system, expert knowledge is usually divided into many separate independent rules or entities. The knowledge representation is transparent—easy to read and understand.

4. The knowledge base used in an expert system is usually separated from the methods for applying the knowledge to the current problem. These methods are referred to as the *inference mechanism.*

5. Expert systems are usually highly interactive.

6. The output of an expert system can be qualitative rather than quantitative.

7. Expert systems tend to mimic the decisionmaking process of human experts. They can provide advice, answer questions, and justify their conclusions.[13]

Development of expert systems for structural design is actively pursued by the research community.[14] However, it should be noted that at present very few commercial CAD package uses an expert system approach.

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[13] H. Adeli, 1988b.

[14] See H. Adeli, 1988b; H. Adeli and M.M. Al-Rijleh, 1987b; H. Adeli and K.V. Balasubramanyam, *Expert Systems for Structural Design—A New Generation* (Prentice-Hall, 1988); H. Adeli and Y.S. Chen, "Structuring Knowledge and Data Bases in Expert Systems for Integrated Structural Design," *Microcomputers in Civil Engineering*, Vol 4, No. 3 (1989); H. Adeli and D. Hawkins, "A Hierarchical Expert System for Design of Floors in High Rise Buildings," *Computers and Structures*, Vol 41, No. 4 (1991), pp 773-788; H. Adeli and K. Mak, "Architecture of a Coupled Expert System for Optimum Design of Plate Girder Bridges," *Engineering Applications of Artificial Intelligence*, Vol 1, No. 4 (1988); H. Adeli and K. Mak, "Application of a Coupled Expert System for Optimum Design of Plate Girder Bridges," *Engineering Applications of Artificial Intelligence*, Vol 2, No. 1 (1989); F.S. Chehayeb et al., "Innovative Engineering Design," *Microcomputers in Civil Engineering*, Vol 4, No. 1 (1989); M.L. Maher et al., "Expert Systems for Structural Design," in H. Adeli, 1988b; Y. Peak and H. Adeli, "Representation of Structural Design Knowledge in Symbolic Language," *Journal of Computing in Civil Engineering*, Vol 2, No. 4 (ASCE, 1988a); Y. Peak and H. Adeli, "STEELEX: A Coupled Expert System for Integrated Design of Steel Structures," *Engineering Applications of Artificial Intelligence*, Vol 1, No. 3 (1988b).

Optimization Module

As previously stated, design is an open-ended problem and many solutions can satisfy given design requirements and specifications. The determination of the "best" design is sometimes made subjectively. But often it is desirable to come up with a design that fulfills a specific criterion such as minimum weight or cost. Mathematical optimization algorithms for design of realistic structures subjected to realistic design constraints (such as those required by the AISC specifications) have recently been developed.[15] At this time only a few commercial CAD packages (e.g., SODA by Waterloo Engineering Software) have an optimization module.[16]

Some CAD packages provide only member-by-member optimization which is computationally inexpensive (e.g., STAAD III by Research Engineers, Inc.).[17] But member-by-member optimization does not usually result in the minimum weight (or cost) for a whole structure so the full weight saving probably will not be achieved. Grierson and Cameron suggest combining the member-by-member optimization module with a formal optimization algorithm as an effective strategy for microcomputer-based optimal design of structures.[18]

Other Features

Some applications may require a CAD package that can smoothly interface with common general purpose software such as a computer-aided drafting package (e.g., AutoCAD™), a spreadsheet program (e.g., Lotus 1-2-3™), a data base management system (e.g., dBASE III™), or a text editor. It may also be necessary to get a CAD program that can execute in a multiuser environment through a local area network (LAN).

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[15] For examples see S. Abuyounes and H. Adeli, "Optimization of Steel Plate Girders Via General Geometric Programming Technique," *Journal of Structural Mechanics*, Vol 14, No. 4 (1986); S. Abuyounes and H. Adeli, "Optimization of Hybrid Steel Plate Girders," *Computers and Structures*, Vol 27, No. 2 (1987); H. Adeli and K. Chompooming, "Interactive Optimization of Multispan Plate Girders," *Microcomputers in Civil Engineering*, Vol 3, No. 3 (1988a); H. Adeli and K. Chompooming, "Interactive Optimization of Nonprismatic Girders," *Computers and Structures*, Vol 31, No. 4 (1986b); H. Adeli and K.V. Balasubramanyam, "Interactive Layout Optimization of Trusses," *Journal of Computing in Civil Engineering*, Vol 1, No. 3 (ASCE, 1987); H. Adeli and Y. Ge, "A Dynamic Programming Method for Analysis of Bridges Under Multiple Moving Loads," *International Journal for Numerical Methods in Engineering*, Vol 28 (1989); H. Adeli and K. Mak, "Interactive Optimization of Plate Girder Bridges Subjected to Moving Loads,"*Computer Aided Design*, Vol 22, No. 6 (1990).

[16] D.E. Grierson and G.E. Cameron, *SODA—Structural Optimization Design and Analysis* (Waterloo Engineering Software, 1987).

[17] *STAAD III Integrated Structural Design System* (Research Engineers, Inc., 1987).

[18] D.E. Grierson and G.E. Cameron, "Microcomputer-Based Optimization of Steel Structures in Professional Practice," *Microcomputers in Civil Engineering*, Vol 4, No. 4 (1989).

5 BENCHMARK TESTS

After initial screening of the software packages using the criteria proposed in Chapter 3, and perhaps screening more critically using the benchmark criteria presented in Chapter 4, the user may use two tests for overall evaluation of a select number (say three) of the more promising software packages. In doing so, the following characteristics should be compared:

1. Capability of solving the design problem

2. Accuracy

3. Efficiency (computation time).

Example Problems Provided by Vendors

Vendors usually provide example problems that can be solved by the specific software package being demonstrated. The software package can usually solve these examples in the most efficient and convenient way. Also, these examples often try to highlight the unique capabilities of the software package. Example problems provided by one software developer should be run and tested by other software packages the user is considering for purchase.

Examples From Design Manuals and Textbooks

Design manuals such as the *AISC Manual of Steel Construction - Allowable Stress Design* (AISC, 1989), *Manual of Steel Construction - Load and Resistance Factor Design* (AISC, 1986), and *Notes on ACI 318-77 Building Code Requirements for Reinforced Concrete* (Portland Cement Association [PCA], 1980) provide sample design solutions. A select number of these design solutions should be used in benchmark tests. This will help the potential user determine how well the software packages being evaluated incorporate the intent of the particular design code.

Some design textbooks[19] contain interesting and unusual examples intended to challenge students. These examples can be used to test the limits of the software being evaluated.

[19] For steel structure examples see H. Adeli, 1988a, and C.G. Salmon and J.E. Johnson, *Steel Structures—Design and Behavior* (Harper and Row Publishers, 1980); for prestressed concrete structure examples see T.Y. Lin and N.H. Burns, *Design of Pre stressed Concrete Structures*, 3d ed. (John Wiley & Sons, 1981); for reinforced concrete structure examples see E.G. Nawy, *Reinforced Concrete—A Fundamental Approach* (Prentice-Hall, 1985), and G. Winter and A.H. Nilson, *Design of Concrete Structures* (McGraw-Hill Book Co., 1979); for reinforced masonry examples see R.R. Schneider and W.L. Dickey, *Reinforced Masonry Design* (Prentice-Hall, 1980).

6 TABULATING THE EVALUATION INFORMATION

The results of the initial screening defined in Chapter 3 can be summarized as in the example of Table 1. Each software package is rated as A (acceptable) or U (unacceptable) on each criterion. A package should be rated A on all criteria to pass the initial screening. It should be noted that this rating procedure is subjective to some extent. It also depends on the particular design category and situation. For example, if a maximum budget of $2000 is allotted for a particular design category, any package with a price greater than that is simply considered unacceptable.

For all programs passing the initial screening, it is helpful to organize the information on a worksheet similar to the one in Table 2. Each column heading represents one of the benchmark criteria discussed in Chapter 4. Each software package is rated from 1 to 10 on each criterion. Each criterion is assigned a weighted value by the evaluator (sample values are shown below the table). Table 2 also provides a weighted average of these criteria. The last three columns are left blank at this stage.

The results of benchmark tests (from Chapter 5) performed on the software packages that passed the initial screening can be summarized as in the example of Table 3. The package with the shortest computation time is generally considered the most efficient. Notice, however, that Package 4 was rated least efficient: although it performed the first five examples faster than the other two packages, it could not solve the sixth. The overall importance of these findings is decided by the evaluator. Failure to perform an example problem may disqualify the package for one use but not another. The resulting efficiency ratings are entered into the appropriate spaces on the Table 2 worksheet.

Table 1

Example of Tabulated Information From Initial Software Screening

Software Package	Criteria						Consideration for Further Evaluation
	a	b	c	d	e	f	
1	A	A	U	A	A	A	NO
2	A	A	A	A	A	A	YES
3	A	U	A	A	A	A	NO
4	A	A	A	A	A	A	YES
5	A	A	A	A	A	A	YES
6	A	A	A	A	U	A	NO

a: DOS compatibility
b: Graphics capability
c: Software developer qualification and track record
d: Documentation
e: User support
f: Cost

A: Acceptable
U: Unacceptable

Table 2

Example of Initial Screening Ratings Recorded on Evaluation Worksheet

Software Package	Criteria										Wt. Avg.*	Eff. Rank	Cost ($)	Final Rating
	a	b	c	d	e	f	g	h	i	j				
2	7	7	8	6	6	6	9				6.72			
4	5	6	7	5	7	6	6				5.64			
5	9	10	8	4	8	6	8				7.76			

Benchmark Criteria	Weighted† Value	Description
a	(100)	User interface issues
b	(60)	Interactive graphics
c	(60)	Data entry facility
d	(40)	Portability
e	(60)	Redesign management
f	(30)	Programming environment
g	(30)	Special considerations
h§	(0)	Expert system module
i	(15)	Optimization module
j	(20)	Other features

* The weighted averages are the sum of the criteria values multiplied by their weighted value, and then all divided by the total of the weighted values.

† The weighted values are determined by the person evaluating the software based on the importance he places on each criteria.

§ Criteria h, i, and j may be skipped if these are not of interest to the evaluator.

Table 3

Example of Software Efficiency Ranking Based on Computation Times (in Seconds) for Example Problems

	Software Package		
	2	4	5
Example 1	2	1	2
Example 2	5	4	5
Example 3	7	5	9
Example 4	10	9	11
Example 5	27	21	28
Example 6	267	*	273
Efficiency Rank	1	3	2

* The software package cannot solve this example satisfactorily.

The final rating is based on all the information entered on the Table 2 worksheet. Table 4 shows the packages rated according to all evaluative criteria for comparison at a glance. The last column is reserved for the evaluator's final ranking. It should be noted that some of the benchmark criteria naturally conflict to some extent. For example, a high degree of interactivity is achieved at the expense of efficiency. Also, generally speaking, symbolic processing and AI-based expert systems are less efficient than conventional CAD programs. The user must determine which of the conflicting criteria is most important, and this will depend on the individual situation.

Table 4

Example Tabulation of All Software Ratings for Final Evaluation

Software Package	Criteria										Wt. Avg*.	Eff. Rank	Cost ($)	Final Rating
	a	b	c	d	e	f	g	h	i	j				
2	7	7	8	6	6	6	9				6.72	1	1100	2
4	5	6	7	5	7	6	6				5.64	3	995	3
5	9	10	8	4	8	6	8				7.76	2	1200	1

Benchmark Criteria	Weighted† Value	Description
a	(100)	User interface issues
b	(60)	Interactive graphics
c	(60)	Data entry facility
d	(40)	Portability
e	(60)	Redesign management
f	(30)	Programming environment
g	(30)	Special considerations
h§	(0)	Expert system module
i	(15)	Optimization module
j	(20)	Other features

* The weighted averages are the sum of the criteria values multiplied by their weighted value, and then all divided by the total of the weighted values.

† The weighted values are determined by the person evaluating the software based on the importance he places on each criteria.

§ Criteria h, i, and j may be skipped if these are not of interest to the evaluator.

7 SUMMARY

The structural design community has recently seen a flood of commercially available structural design software. In general these tools offer great potential to improve the efficiency and effectiveness of Army structural designers, but selecting the appropriate CAD program requires a thorough evaluation of a program's strengths and weaknesses. This report presents a methodology for evaluating the merits of several software packages being considered for a particular design category. This evaluation begins with an initial screening of available software based on a review of industry and professional literature. The packages that look most promising are then tested against a series of appropriate benchmark criteria and tests. Although some subjectivity will enter into decisions about certain criteria, this methodology will result in a largely objective rating of the merits of each package. In this way the structural engineer can select the CAD program most appropriate for his or her needs.

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APPENDIX: Relevant USAWES Structural Design and Analysis Software for Microcomputers

Program No.	Name	Description
X0001	BEAM1	Plane Beam Analysis by Direct Stiffness
X0002	TRUSS	Plane Truss Analysis by Direct Stiffness
X0003	FRAME	Plane Frame Analysis by Direct Stiffness
X0004	GRID	Grid Analysis by Direct Stiffness
X0005	STRUSS	Space Truss Analysis by Direct Stiffness
X0006	GFRAME	Analysis of Planar Rigid Frames
X0007	PTRUSS	Plane Truss Analysis by Stiffness Matrix
X0008	CGFA	Concrete General Flexure Analysis
X0009	CGFARD	Round Section Data Generator for X0008
X0010	GIRD1	Non-Composite Girder Analysis
X0011	GIRD2	Composite Girder Analysis
X0012	INFORD	Influence Ordinates, Areas on Continuous Beam
X0013	WTRAIN	Analysis of Moving Loads, Simple Spans
X0015	BEAMS	Shear, Moment, and Deflection
X0016	BEAMW	Beam Analysis for Complex Geometry & Loads
X0017	STAB	Concrete General Stability Analysis
X0018	GAIP	Computes Geometrical and Inertial Properties
X0019	SKNPL	Design/Analysis of Composite Skinplate
X0020	2DFRAME	Analysis of 2D Frames with In-Span Loads
X0022	EFFRAM	Plane Frame on an Elastic Foundation
X0030	CFRAME	Interactive Graphic Plane Frame Analysis
X0031	CWALSHT	Sheet Wall Analysis/Design Program (CASE)
X0032	BMCOL77	Numerical Analysis of Beams & Beam-Columns
X0050	CBEAMC	Analysis of Beam Column Structures with Nonlinear Supports
X0052	CTABS80	3D Analysis of Building Systems
X0059	CASM	3D Modeling and Load Generation
X0061	CGSI	Concrete General Strength Investigation by ACI Code 318-77
X0062	PCAUC	Strength Design of Reinforced Concrete
X0063	CSMT	Moment, Shear, and Thrust Calculation
X0065	CBNTBM	A 2D Beam Column Analysis Including Soil Structure Interaction
X0066	CSTR	Concrete Strength Investigation and Design
X0067	CASTR	Concrete Strength Investigation and Design in Accordance with ACI Code 318-83
X0068	CGRID	Analysis of Planar Grid Structures

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